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METHODOLOGY AND TEST PROCEDURES FOR EVALUATING NEW ROOFING MATERIALS

by H.O. Laaly and H.E. Ashton

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H.O. Laaly* and H.E. Ashton*

ABSTRACT

Worldwide, there are more than 40 tests to assess the properties of nearly 400 conventional and new roofing products that exhibit wide ranges in a given property. New roofing materials can be divided into six distinctly different groups:

1. Hot applied rubberized asphalts
2. Cold applied liquid membranes
3. Prefabricated elastomeric sheeting
4. Flexible polyvinyl chloride (PVC) membranes
5. Prefabricated, reinforced, modified bituminous membranes
6. Sprayed polyurethane with weather-resistant top coats

Each of these groups has its own specific characteristic properties that must be taken into consideration at the design stage. Test procedures were selected or, where necessary, developed to quantify properties before and after subjecting the materials to accelerated exposure conditions.

This paper highlights the state of evaluating new roofing materials and describes test methods for this task. The concept and rationale of selecting tests for the different types of membranes and the tentative limits for various properties are discussed.

KEY WORDS: Roofing, Methodology, Evaluation, Roofing Membrane, Waterproofing, Roofing Materials, Membrane Lap-Joints, Specifications, Standards.

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* Research Officers, Materials Section, Division of Building Research, National Research Council of Canada, Ottawa, Canada K1A 0R6.

RÉSUMÉ

Il existe dans le monde plus de 40 essais pour évaluer les caractéristiques d'environ 400 produits traditionnels ou nouveaux de couverture. Pour une propriété donnée, les caractéristiques sont très différentes selon le produit. Les nouveaux matériaux de couverture peuvent être divisés en six groupes distincts :

1. les asphaltes caoutchoutés appliqués à chaud
2. les produits liquides appliqués à froid
3. les revêtements préfabriqués en élastomère
4. les membranes flexibles en chlorure de polyvinyle (PVC)
5. les membranes en bitume préfabriquées, renforcées ou modifiées
6. les films de polyuréthane pulvérisé avec couches résistant aux intempéries

Chacun de ces groupes a des caractéristiques qui lui sont propres et qui doivent être prises en considération au moment de la conception. Les essais ont été choisis ou, lorsque cela a été nécessaire, ont été établis pour évaluer les caractéristiques avant et après exposition des matériaux à des conditions ambiantes très rigoureuses.

Cette communication indique comment évaluer les nouveaux matériaux utilisés pour les toits et décrit les méthodes d'essai. Elle indique quel essai choisir pour différents types de membrane et quelles sont les limites de diverses caractéristiques.

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INTRODUCTION

Never before have so many new roofing materials been introduced to the roofing industry as during the past decade. The reasons for this are many:

1. Difficulties in overcoming the problems associated with the use of bituminous Built-Up Roofing (BUR) membranes and the increasing rate of premature failure of BUR membranes applied over insulation;
2. Increasing costs of labour and materials for the conventional roofing system due, for the latter, to the high proportion of petroleum-based materials used;
3. Factory prefabrication of membranes in which quality is readily controlled during manufacture;
4. Ease, speed and cleanliness of prefabricated membrane application as compared with BUR. Application of BUR is labour intensive and highly weather dependent, while many new materials can be applied throughout the year; and
5. Advances in polymer science and rubber technology and development of criteria for sound roofing performance.

Regardless of the reasons, the volume of these new materials has caused problems of selection for architects, engineers, designers and construction managers. As most of the nearly 400 new roofing materials have a limited service record, users have been forced to rely upon the manufacturers' claims, which unfortunately are not justified in all cases.

To help ease this situation, the Building Materials Section of the Division of Building Research, National Research Council Canada, has, for the past five years, been evaluating these new materials for a Federal housing agency faced with requests for acceptance of them. Because the materials are new to roofing it was necessary, in some cases, to adapt tests used for other materials or to develop new evaluation methods.

There is, of course, considerable roofing research being done in many countries, the results of which appear in a variety of journals. Two recent lists of roofing research articles, one published by the U.S. Dept. of Energy (1) and the other by the U.S. Dept. of Commerce (2), should be of help in locating papers on the subject, although the latter

contains many items only slightly related to roofing. Another report (3) from the first agency describes research that is still needed in the roofing area.

Based on work carried out at DBR, specifications, test methods and application procedures have been prepared by the Canadian General Standards Board for most of these products. This paper summarizes this activity.

CLASSIFICATION

The term "single ply roofing" has been used as a collective expression for these new roofing materials, but it does not apply to those that are made into a prefabricated membrane with two or more layers, while some of the liquid materials can be applied in more than one coat. Because the chemical composition and physical properties vary so widely, and because there are not yet performance-based criteria applicable to all, it was considered necessary first to group the materials into several generic classes. The following classification was adopted and has proven helpful in evaluating the materials and preparing specifications:

1. Hot applied rubberized asphalts;
2. Cold applied liquid membranes;
3. Prefabricated elastomeric sheeting;
4. Flexible poly(vinyl chloride) (PVC) membranes;
5. Prefabricated, reinforced, modified bituminous membranes; and
6. Sprayed polyurethane foam with weather-resistant top coats.

There are, of course, other related materials that do not fit into these classes, such as prefabricated foam composites and corrugated rigid roofing panels, as well as a host of roofing accessories. While these materials are also important they are not discussed in this paper because of time and space limitations.

The six classes will be described briefly to aid in understanding the behaviour of the various materials in different environments, to indicate when there may be interactions between components, and to give the rationale for the classification.

1. Hot applied rubberized asphalts - The rigidity and brittleness of asphalt at low temperatures and the availability of millions of discarded tires led to the development of this class of materials for use as flexible pavement and as a monolithic roofing and waterproofing membrane. In general, it consists of rubber, which may be virgin or reclaimed, dispersed in asphalt. To optimize the mechanical properties of the mixture only a small per cent of synthetic rubber is required, but greater quantities of reclaimed rubber must be added. Other materials, such as oils, along with clay or limestone fillers,

are also used in the product. Composition, mixing, heating time and temperature must be closely controlled during production. The finished product is made into 10- to 20-lb cakes wrapped in low density polyethylene that can be stored indefinitely. On the job site the packages can simply be melted in a kettle because the polyethylene melts with the rubberized asphalt, improving its physical properties. A double-jacketted kettle with high boiling mineral oil between the walls and a temperature controlling device are essential to avoid localized overheating and thermal degradation during application.

2. Cold applied liquid membranes - Materials in this class may contain one, two or more components. Some are emulsion- or dispersion-based while others are solutions. It should be recognized that some of these liquids are not stable indefinitely as emulsions may break or multi-component materials gel. This aspect is not covered in this paper. Materials in this class may be based on modified asphalt, coal tar pitch, and various types of resins or elastomers such as polyurethane, dibromobutadiene, silicone or acrylic. Sometimes white pigment or aluminum flakes are added to reflect solar radiation, at other times mineral granules or sand are introduced in the still-wet coating for protection from radiation.

3. Prefabricated elastomeric sheeting - These membranes are based on several types of elastomer with ethylene-propylene-diene monomer (EPDM) and polyisobutylene (PIB) predominating. Other rubber and rubber-like materials included in this category are: chlorinated polyethylene (CPE), chlorosulfonated polyethylene (CSPE) and polychloroisobutylene (PCIB). These sheets with a nominal thickness of 1 to 2 mm may or may not be fiber reinforced. The reinforcing is sometimes incorporated as a fabric laminate, or nonwoven fiber can be used for the backing which also serves as the reinforcement and, when applied over a rough substrate, as a cushion. The ultimate elongation and breaking strength of the reinforced membranes depend on the type and quantity of reinforcement. Because most contain carbon black or a few other pigments they can be exposed to solar radiation, unless otherwise specified by the manufacturer.

4. Flexible poly(vinyl chloride) (PVC) membranes - This type of roofing membrane, which has a nominal thickness of 1 to 2.5 mm, was introduced in Europe and is now in widespread use. Loss of plasticizer, shrinkage due to stretch relaxation and lap joint delamination were some of the early shortcomings that have now been virtually solved by incorporating more permanent plasticizers and glass fiber reinforcing and by the use of hot-air instead of solvent welding of the lap joints. The fact that flexible PVC sheet can be either fully adhered, spot bonded, or loosely laid, ballasted and mechanically fastened at the perimeters, allows architects or designers to choose the system they prefer. Flexible PVC sheet is also available with flexible foam or nonwoven polyester fabric backing, which also acts as a cushion to accommodate surface roughness of the substrate. Because PVC sheet contains pigment and UV

stabilizer it can be exposed to solar radiation, but protection with gravel increases its service life expectancy.

5. Prefabricated, reinforced, modified, bituminous membranes - Because of the composition and method of application, this class of materials is closest to conventional built-up roofing. Its thickness, 2 to 4 mm, is considerably lower, however, than BUR which can range from 6 to 10 mm. The membranes can be fully adhered to the roof deck either by application of a suitable asphalt adhesive or by using a propane torch to melt the underside of the film while unrolling it. Non-blown bitumen is modified with synthetic or natural rubbers and sometimes with a polymer, such as isotactic polypropylene, to improve the properties of the bitumen. The reinforcement may be woven or non-woven fabric consisting of glass fiber, polyester, nylon, rotproofed jute or other natural fibers, or any combination thereof. This class of membrane is usually applied over a Base sheet, which may be similar to or different from the Cap sheet. In many cases, the membrane is surfaced with a reflective metal such as embossed aluminum, copper or sometimes stainless steel. In some geographic areas, mineral slates or granules are embedded to provide protection against weathering while on other products coloured mineral granules are used instead for esthetic reasons. The joints are made by using one of the following methods:

   a) Propane torch with single or double nozzle;
   b) Electric hot-air gun;
   c) Double-sided adhesive tape covered with release paper; and
   d) Adhesive, 3 to 4 in. wide, factory applied along the machine-direction edge of the membrane.

   In some cases, ordinary hot asphalt is used to make the joint. There have been some joint delaminations where the asphalt became brittle at low temperatures or was not compatible with membrane components.

6. Sprayed polyurethane foam and weather-resistant topcoats system - The use of polyurethanes as roofing materials has become more common in the last 10 years. As described under class 2, asphalt and coal-tar pitch have been modified with urethanes and applied as a liquid membrane. With the recent need for energy-saving measures in-situ spray application of polyurethane foam insulation to a thickness of 50 to 100 mm has been introduced as a method of saving labor as well as energy. The system can be applied directly to the roof deck or, in retrofitting, over existing BUR. Because polyurethane foam, by itself, is not resistant to ultraviolet light it must be protected. Silicone, acrylic or polyurethane pigmented coatings are sprayed on, preferably in two applications of 15 to 20 mils each. Immediately after the second coat fine mineral granules are applied to increase the abrasion and weather resistance of the system.

There are several precautions that must be observed when using these systems. As polyurethanes are made by the reaction of hydroxyl-containing compounds with isocyanate materials and a blowing agent the correct mixing ratio has to be maintained to produce the right kind of foam. A density of 2.5 to 3 lb/ft^3 is normally recommended for roofing so it will have load bearing characteristics and will not be damaged by impact (including pecking by birds). One of the major problems with the coated foam system is its vulnerability to blister formation in the coating. To prevent blistering the surface skin of the polyurethane foam must be bone dry when the protective coating is applied. There is also some controversy about whether or not a vapour barrier should be used under the foam.

Because spray application is used for both the foam and the coating, this class is more easily applied than the others to parabolic, hyperbolic, or other non-conventionally shaped roofs.

BASIS FOR THE EVALUATION OF NEW ROOFING MATERIALS

Because of the lack of knowledge about these materials and their limited history of usage, the properties required of a waterproofing membrane and the conditions of use had to be considered, in addition to the properties of the different classes, when deciding upon the evaluation process. Properties of membrane liners for water reservoirs, canals and similar bodies of water are well covered in Technical Report No. 113 of the U.K. Water Research Centre (4), a report issued a few years after the inception of the DBR program. Consequently, only the points that apply to roofing will be considered in this paper.

As with all waterproofing membranes, those used on roofs must be resistant to moisture since their prime function is to keep water out of the structure. With some materials moderate permeability to water vapour is claimed to be an advantage but absorption of more than a few per cent of water is indicative that a material's characteristics are likely to deteriorate when there is contact with water for long periods. In moist climates membranes that will be used under the insulation are likely to be more exposed to water than those used on conventional roofs but will not be subjected to temperature extremes. Roofing covered with gravel or paving stones is shielded from solar radiation and wind-driven objects but not from rapid temperature changes. Conditions are most severe for materials that will be completely exposed in service because several studies have shown that with organic materials the combined effect of ultraviolet light, oxygen and high temperature is much greater than the sum of their individual effects.

Regardless of whether or not roofing membranes will be covered in service, they must be resistant to penetration because they may be subjected to accidental abuse by workers during installation. Owing to the large area of many roofs, the mechanical properties of a roofing membrane must be adequate to resist the large tensile loads that

may be concentrated at certain locations. Also, except for liquid-applied materials, the sheets must be joined to cover the area necessitating sound joints. Because polymeric materials are brittle below their glass transition temperature, membranes intended for use in cold climates must be made from materials that retain reasonable flexibility at low temperatures.

Based on the foregoing considerations the tests selected for evaluating the six classes were mainly concerned with establishing the mechanical properties of the materials and the effect of temperature extremes and moisture on these properties. For most of the materials applied in sheet form, the conventional tensile test was used with the testing rate for rubbers specified in ASTM Method D 412 as 20 in./min (8.5 mm/sec) corresponding to an initial strain rate of 5 in./in. (mm/mm) min. This rate is different from that given in D 882 for thin plastic sheeting where the rate varies with the amount of elongation at break since a fast rate is known to be equivalent to reducing the test temperature, i.e., making the material more brittle. In the latter case the initial strain rate is 10 in./in. min for plastics that break at elongations over 100 per cent but only 0.5 in./in. min for those with elongations of 20 to 100 per cent. However, because tensile results obtained at different rates are not comparable, the intermediate speed selected was most widely applicable to the broad range of roofing materials under investigation.

Several tests have been used to evaluate the mechanical properties of class 1 - rubberized asphalts - and especially to determine if the modification had really improved the properties of asphalt. The simplest is the bend test at low temperatures. Ductility was measured with specimens shaped in accordance with ASTM Method D 113 but using a cold chamber instead of a water bath and a tensile tester because the test was conducted at -25°C. Two other tests, the crack-bridging test at -25°C and the toughness-tenacity test, were also investigated for their suitability in evaluating rubberized asphalts.

Exposure to heat is commonly used as a means of accelerating natural ageing, although with many materials the degree of correlation between artificial and natural behavior is not high. In this study specimens of the materials were subjected to elevated temperatures selected, in some cases, from specifications or test methods for similar materials. Low temperature flexibility and mechanical properties were usually measured again after the heat test and a suitable conditioning period, to determine the effect of heating.

The response to water was determined by measuring dimensional and weight changes caused by water immersion. The temperature of the water was frequently elevated, for two reasons - to accelerate the normally low rate of water absorption, and to simulate the high water temperature that can occur in ponds on roofs. As with dry heat, the effect of water immersion was detected by remeasuring tensile or other physical properties.

Several methods have been used to determine whether materials in different classes might be punctured during installation or service. Cone penetration with load application at a uniform rate by means of a tensile tester was used with PVC membranes. Elastomerics and vinyls were subjected to the impact test, ASTM D 2794, which is commonly used on organic coatings. The last two groups, as well as cold-applied liquids, were also evaluated by a static test in which a loaded rod is pressed against the sheet, as shown in Figure 1. Both a small-scale and a large-scale apparatus were developed to investigate whether an applied load would damage a membrane when twisted to simulate the turning of a heel or a wheelbarrow tire. The tests are, in effect, equivalent to one used for many years in the British coatings industry (5) to determine when a film has solidified completely (called "hard-dry" or "through-dry" time).

EXPERIENCE WITH EVALUATION METHODS

Owing to the great number of materials and an occasional request for special attention to a particular material or problem, all the methods have not been applied to all the materials under test, or even to all six classes . Because the work is still continuing, the following review is essentially a progress report.

Mechanical Properties - As stated earlier, rubberized asphalts usually contain other ingredients, some of which are added to soften the material and increase its tack. As a result most rubberized asphalts are too soft to be tested in a tensile machine, especially at room temperature. Hence, other methods have to be used to evaluate their mechanical properties. The DBR studies have included ductility using the asphalt-specimen shape prescribed in ASTM Method D 113 but elongating the specimen in a tensile machine at -25°C at various rates, crack bridging at -25°C, and toughness-tenacity at room temperature.

The last-named test, which involves pulling a brass hemisphere from the matrix, is supposed to demonstrate that rubber has improved the tensile properties of asphalt. When the first tests in this study were run, however, it was found that the smooth hemisphere was pulled out of half the products at low loads and with none of the specimen adhering to it while with the others some of the rubberized asphalt did adhere and considerably higher values were obtained. Investigation of this behaviour led to the replacement of the hemisphere by a one-in. wide threaded rod with a rounded end to which all samples adhere to some extent.

In the original method, the total area under the load vs time curve was called 'toughness' and the area under the additional peak, resulting from the rubber component, 'tenacity.' This work, however, used the Ontario Ministry of Transportation and Communication procedure of calculating the ratio of the total area to the load at the first, or asphalt, peak. The result is, in effect, only a modified elongation since in.-lb divided by lb yields inches. When the toughness values

derived from the total areas under the curves were compared it was found that Types I, II and III asphalt were tougher than four out of eight products that had had rubber added, supposedly to increase toughness. Even the different asphalt types were not ranked in the correct order. The ratio calculation did at least place the asphalts among the lower ranked rubberized asphalts. Tests are now being run to determine whether the anomalous results from the toughness-tenacity test are due to the bitumen in the rubberized material differing from the straight asphalt or to the method itself.

By contrast, the simple elongation measurement based on ASTM D 113 rated all rubberized materials above unmodified asphalt, as would be expected. The method also allows evaluation of brittleness by measuring the decrease in elongation with increasing elongation rates. The low-temperature bend test, while familiar and inexpensive, was suitable only for detecting gross failures using a test temperature of -25°C. That the test is not very selective is shown by the fact that four out of five rubberized asphalts failed at -37°C while only one failed when the temperature was raised by 12 C deg.

The crack-bridging test was developed to determine whether rubberized asphalts, or other fully adhered membranes, can resist the opening and closing of small cracks that may develop in concrete roof decks some time after application of the liquid coating. The molten material is applied to the asphalt-primed surfaces of two concrete blocks that touch along one side. After overnight conditioning at room temperature the assembly is cooled at -25°C. The blocks are then pulled apart so that after one hour the distance between them is 1/8 in. (3.2 mm); they are then pushed back together at the same rate. At the end of 10 extension and compression cycles the membrane is examined for cracking, splitting and loss of adhesion. In the DBR tests a tensile machine capable of cycling was used to determine the load in each phase of the cycle.

Examination showed that only one specimen, which had been immersed in water overnight before testing, exhibited failure. Even one product that had failed the undemanding mandrel test at -25°C did not crack, split or lose adhesion. Measurement with a tensile machine of the loads required to spread the blocks was more informative than simple qualitative evaluation of the cycled specimens. The load in the second cycle is another measure of tensile strength while the change in load from the second to the tenth cycles gives an indication of fatigue resistance. The significance of the compressive loads is more doubtful and not as easy to measure because the blocks tend to touch more than originally, thus giving higher loads in the first few cycles.

The low temperature flexibility test was more discriminating with some of the other classes of materials. In class 2, cold-applied liquids, two out of six samples failed at -10°C while the remainder passed at -30°. For class 5, four passed at -30°, nine that failed at that temperature passed at -15 or -20°, six failed at both exposures, and

another seven were not tested at the lower temperatures because they had already failed at -10 or -15°. On the other hand, all the elastomeric (class 3) materials tested passed at -30°. Whether these results are related to field performance is not yet established but it might be expected that the modified reinforced bituminous membranes that exhibited poor flexibility at only -10 to -15° would not survive many Canadian winters.

The poor flexibility of the two class 2 materials was confirmed by low elongations and tensile strengths when they were subjected to the tensile test. Similarly, elongations of 250 to 1000 per cent for the elastomers and 280 to 350 per cent for PVC agreed with all these samples passing the bend test at the lowest temperatures used. The correlation between the bend and tensile test results was not nearly as good with class 5 materials. This was probably due to their compositional differences which range from reinforcement with synthetic fibers or rubbers to aluminum or copper overlays.

The advantage of the tensile test is its ability to distinguish differences among materials with high flexibility. For instance, two reinforced vinyls had elongations comparable to those of the unreinforced samples but their tensile strengths, especially that of the material containing glass-fiber were significantly lower. There were similar differences in tensile strengths among class 3 materials, with low strength not always associated with high elongation, or vice versa. Again, one would suspect that those with lower elongation combined with lower tensile strength would be inferior in practice.

Water Immersion - Immersion conditions varied from 22 hours at boiling, to seven days at 50°C, to as much as seven months at room temperature. Because, except for class 2, most of the materials did not differ greatly within each class, the direct determination of weight and length change is, in general, suitable only for identifying materials that absorb excessive quantities of liquid or swell abnormally. Work to determine whether the small differences within a group are significant would require a more sensitive absorption procedure such as the quartz spiral technique (6). The ductility and toughness tests for rubberized asphalts are not suitable for detecting the effect of water immersion because the large size of the specimens retards absorption.

Immersion of PVC in 50°C water for seven days illustrates some of the problems that can be caused by the use of heat to accelerate the weathering process. In this case, specimens of vinyl sheet cut across the machine direction expanded, as expected, after immersion in the hot water but those cut in the machine direction shrank. It was established that the cause of the shrinkage was relaxation of the internal stress induced by the rolling process. This shrinkage must be taken into account not only when using the accelerated test but in the installation procedure.

Two reinforced PVC's absorbed more water than three out of four

unreinforced samples but their length changes were much less. At first glance, the low dimensional change might appear to be beneficial but when considered with the relatively high weight changes it could indicate that when the glass-reinforced material has been in service for some time a stress will result at the glass-resin interface because of the differences in expansion and contraction. This mechanism has been shown (7) to be one of the causes of failure of glass-reinforced polyester plastics (GRP).

Comparison of mechanical properties before and after immersion showed that nearly six months in water at room temperature had no effect on the tensile strength of two unreinforced vinyls but decreased elongation by 10 per cent. When dried films of seven cold-applied liquid roof coatings were similarly immersed, the elongation of most of them was again more affected than the tensile strength. As indicated in Table 1, the two materials that decreased in elongation to 24 per cent of their original values also had the largest weight and dimensional changes (Figure 2). For all seven, the correlation coefficient between the per cent changes in elongation and length was 0.78 which is high enough to establish reasonable correlation while the rank correlation coefficient for the same paired comparison was 0.86 and statistically significant at the 95 per cent confidence level. The correlation coefficient for elongation and weight changes was 0.66 per cent but tensile strength changes caused by immersion did not correlate with either weight or dimensional changes, whether calculated on the basis of actual values or on rank. In contrast to these cold-applied materials, where both tensile strength and elongation at break decreased on long-term immersion at room temperature, six elastomeric membranes, some of which were reinforced, exhibited differing responses to high temperature water. Two decreased in elongation but increased in breaking strength which might be an indication of brittleness. One decreased in strength but increased in elongation, one did not change strength but increased in elongation, and one decreased in both properties. The only membrane to increase in elongation and strength had the lowest water absorption (Table 2).

Two manufacturers' class 5 materials containing glass or non-woven polyester were also subjected to tensile tests before and after immersion in hot water. It was found that the glass-fiber reinforced membrane from one company was much more anisotropic in both tensile strength and elongation, the former being higher in the machine direction and the latter in the cross-machine direction. In addition, although the elongation was much higher than that of the other company's products, whether glass or polyester reinforced, it decreased by 70 to 80 per cent upon immersion for five days while the other's membranes retained the same elongation, within experimental error. The second manufacturer's glass-veil reinforced material was considerably lower in tensile strength than the corresponding membrane containing glass-fiber but both had the same low elongation. This variability is due, in part, to the type of asphalt, the kind of reinforcement and the method of production.

One aspect that has received considerable attention in this evaluation program is the strength of lap joints made from the sheet-applied membranes. It is, of course, essential that the joints be as strong and waterproof as the membranes between the joints. Consequently, lap-joint specimens have been subjected to the tensile test before and after immersion in hot water and subsequent cycles of freezing and thawing (Figure 3). The results of these tests are being confirmed by natural exposure of joint specimens (Figures 4 to 6). To date, the latter have been examined only visually but the first impression is that many materials that performed poorly in the accelerated tests are already showing signs of failure in natural weathering.

Heat Ageing - Determination of the mechanical properties of PVC membranes subjected to a high temperature also revealed the uncertainties that can arise if a reaction or process different from that occurring in the natural environment takes place at the elevated temperature. When samples of PVC roofing were heated at 163°C for five hours the tensile strength was unaffected, within the accuracy range of the method. This reflected what happened with an unreinforced membrane exposed for eight years but not the experience with a glass-reinforced vinyl, the strength of which increased by nearly 100 per cent after eleven years. The elongation of the first material decreased by 25 per cent upon heating but there was again no change on natural weathering. The elongation of the reinforced PVC decreased by 45 per cent upon heating for five hours while specimens exposed by the manufacturer did not change after five years but decreased by 80 to 90 per cent after eleven years. Thus, the accelerated ageing did not reproduce the increase in tensile strength and the full decrease in elongation of the reinforced material nor the lack of change in the elongation of the unreinforced membrane. PVC films from a third manufacturer showed marked decreases in elongation when heated at 163°C, whether reinforced with polyester fiber or unreinforced, but no long-term results were available for comparison. The elongation changes may be due to decomposition of PVC known to occur at 150°C. Consequently, in the subsequently prepared specification, 24 hours at 130°C was selected as the heat ageing requirement.

It is evident from this brief summary of results that even with materials in the same class there is a wide range in mechanical properties and in the effect of water and/or temperature on them. It remains to be seen whether the performance of the membranes on actual roofs will vary as much.

APPLICATION OF EVALUATION RESULTS

This program was undertaken to assist an agency in accepting new roofing materials for use on houses and other federally financed buildings In spite of the difficulties in trying to assess such a wide range of materials, the results have also been extremely useful in the development of relevant standards. Several material specifications and related

application practices have been issued by the Canadian General Standards Board* and it is hoped to cover the remaining classes in the next eighteen months. When the specifications are first drafted, the values obtained in the DBR tests are submitted for discussion by the responsible committee which then decides on the limits for the requirements selected to evaluate each class of materials. The ultimate use of evaluation methods developed in this program will be their correlation with actual field performance leading to the production of performance-oriented specifications.

CONCLUSION

This paper has reported some of the authors' experiences in evaluating roofing materials introduced on to the market in the past fifteen years. The results have been qualitatively described because there are at least six categories and a few hundred individual products and because any one test, property or class is worthy of a separate paper.

With so many new products proposed for roofing applications it is essential to maintain a balanced view. They should neither be rejected because they have not been in service for twenty years nor accepted automatically as a guaranteed improvement over conventional materials because they are new. Instead, each needs to be assessed on the basis of its properties and the conditions in the proposed application.

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* CGSB Standards should be obtained from the Canadian General Standards Board, c/o Dept. of Supply and Services, 11 Laurier St., Hull, Que. K1A 0S5, Canada.

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TABLE 1

EFFECT OF WATER IMMERSION ON CLASS 2 MEMBRANES

Per cent change after 170 days at room temperature

Sample	Tensile Strength	Elongation	Length	Weight
A	-39.8	-32.8	-2.9	-2.7
B	-30.2	-36.4	-0.35	5.5
C	-51.4	-44.5	1.04	3.2
D	-12.9	-64.1	-5.3	-5.5
E	-32.9	-67.7	4.3	11.2
F	-65.1	-76.2	19.1	34.5
G	-37.1	-76.5	26.4	76.6

TABLE 2

EFFECT OF HOT WATER IMMERSION ON CLASS 3 MEMBRANES

Percent change after 7 days

Sample	Temp. °C	Load at Break	Elongation	Weight
1	60	+64.3	+67.9	1.7
	80	+44.6	+72.3	2.2
	$\bar{x}$	+54.4	+70.1	+1.9
2	60	0	+42.1	5.7
	80	0	+33.6	6.7
	$\bar{x}$	0	+37.8	+6.2
3	60	+ 4.5	0	1.3
	80	-28.7	+14.8	3.3
	$\bar{x}$	-12.1	+ 7.4	+2.3
4	60	+58.8	-11.8	10.3
	80	+55.9	- 0.5	10.5
	$\bar{x}$	+57.4	- 6.2	+10.4
5	60	+130.4	-21.5	30.4
	80	- 4.3	-66.0	54.9
	$\bar{x}$	+ 63.0	-43.7	+42.7
6	60	-37.8	-25.0	3.3
	80	-39.2	-16.7	8.9
	$\bar{x}$	-38.8	-20.9	+6.1

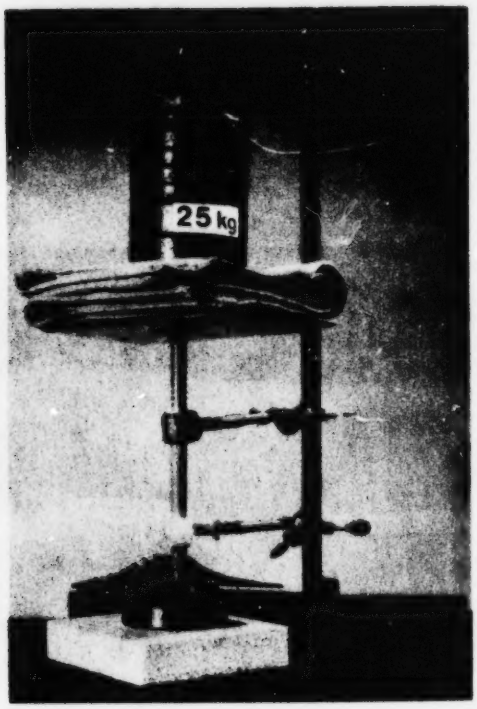

Figure 1. Static puncture test for roofing membranes.

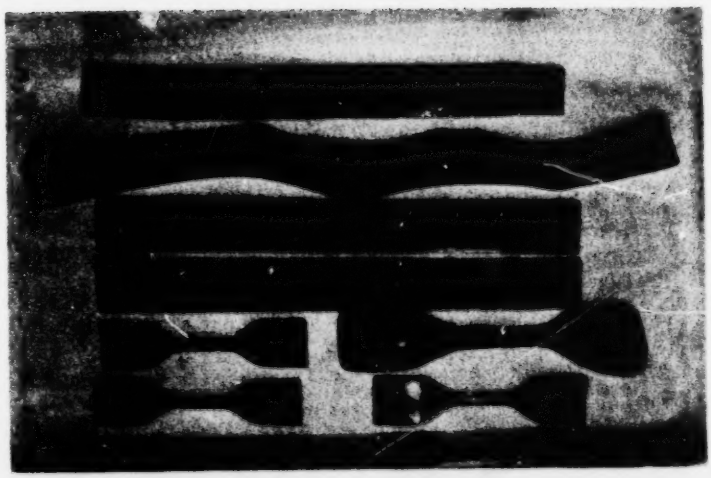

Figure 2. Dimension and Tensile Specimens before and after water immersion. The material exhibiting marked expansion is a cold-applied liquid; the other is a vinyl.

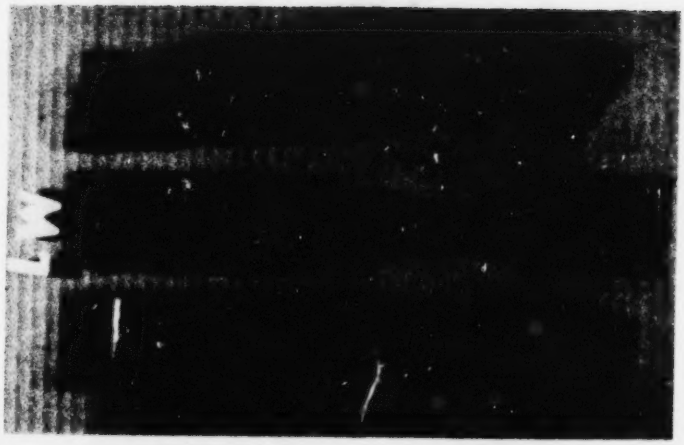

Figure 3. Lap-joint specimens after tensile test showing failure in single thickness but none at the joint.

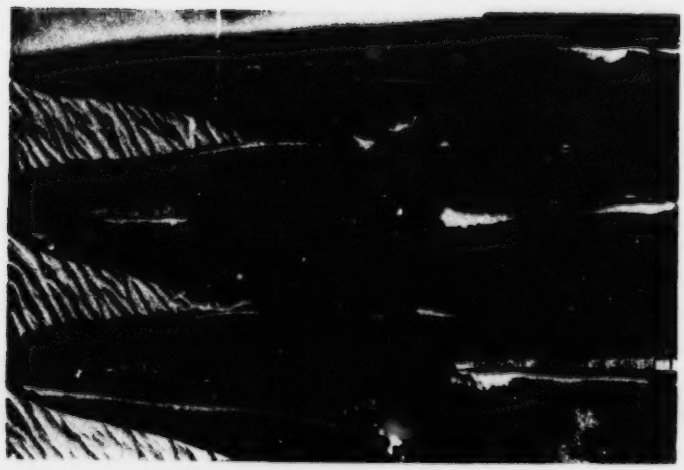

Figure 4. Completely failed lap-joints of polyethylene-surfaced class 5 (intended to be protected) after 3 1/2 years outdoor exposure.

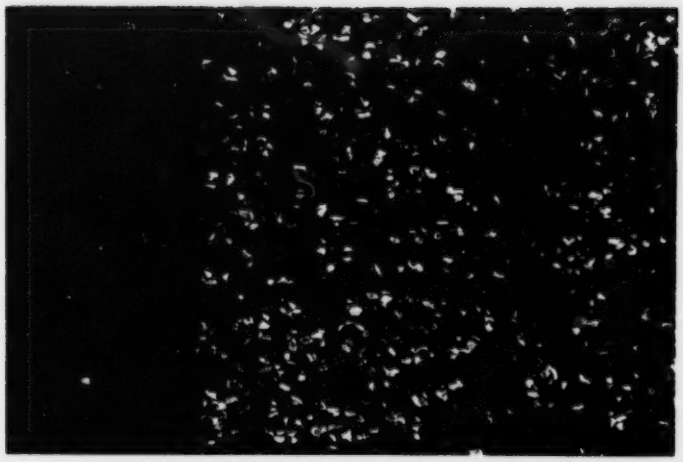

Figure 5. Lap-joints of mineral-surfaced class 5 intact after 3 1/2 years exposure in Ottawa.

Figure 6. Lap-joints of fine mineral-surfaced class 5 after 3 1/2 years showing partial erosion of the mineral surfacing in joint area.